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Science at Saturn from Shallow Entry Probes

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Data from atmospheric entry probe missions at the giant planets could uniquely discriminate between competing theories of solar system formation and the origin and evolution of the giant planets and their atmospheres, providing for valuable comparative studies of giant planets as well as providing a laboratory for studying the atmospheric chemistries, dynamics, and interiors of all the planets including Earth. The giant planets also represent a valuable link to extrasolar planetary systems. For these reasons, a Saturn Probe mission with a shallow probe is ranked by the recent U.S. Planetary Science Decadal Survey as a high priority for a New Frontiers class mission. Atmospheric constituents needed to constrain theories of solar system formation and the origin and evolution of the giant planets could be accessed and sampled by shallow entry probes. Many important constituents are either spectrally inactive or are beneath an atmospheric overburden that is optically thick at useful wavelengths and are therefore not remotely accessible by flyby or orbiting spacecraft. A small, scientifically focused shallow entry probe mission could make critical abundance measurements of key constituents, and could measure profiles of atmospheric structure and dynamics at a vertical resolution that is significantly higher than could be achieved by remote sensing techniques.

Comparative Planetology

Constraints can be placed on formation models of the gas giants by making comparative measurements of gas giants Jupiter and Saturn which requires knowledge of elemental and isotopic composition in the atmospheres of both planets. The required data set requires the combined results from multiple missions to enable truly meaningful comparisons. With the exception of oxygen in the form of water, the Galileo probe provided measurements of elemental and isotopic abundances at Jupiter. NASA's Juno mission to

Jupiter would complete the comparison data set for Jupiter by making measurements of Jupiter's interior structure and global mapping of the deep abundances of water and ammonia, and the interior structure of Saturn could be provided by the Cassini end of life extended mission. To complete the full Saturn data set the elemental and isotopic composition of Saturn's atmosphere is needed and requires *in situ* instruments carried by a Saturn entry probe.

Decadal Survey Vision and Voyages 2013-2022

The recently released United States National Research Council's Planetary Science Decadal Survey "Vision & Voyages for Planetary Science in the Decade 2013-2022" articulates three overarching goals for giant planet system exploration and two levels of science objectives for a Saturn entry probe [1].

Overarching Goal#1 Giant Planets as Ground Truth for Exoplanets: Explore the processes and properties that influence giant planets in the solar system.

Overarching Goal#2 Giant Planet's Roles in Promoting a Habitable Planetary System: Test the hypothesis that the existence, location, and migration of the giant planets in the solar system has contributed directly to the evolution of terrestrial planets in the habitable zone.

Overarching Goal#3 Giant Planets as Laboratories for Properties and Processes on Earth: Establish the relevance of observable giant planet processes and activities as an aid to understanding similar processes and activities on Earth and other planets.

The prioritized science objectives for a Saturn probe mission are defined in the Planetary Science Decadal Survey:

Highest Priority Science Objectives

- determine the noble gas abundances and isotopic ratios of H, C, N, and O in Saturn's atmosphere.
- determine the atmospheric structure at the probe descent location.

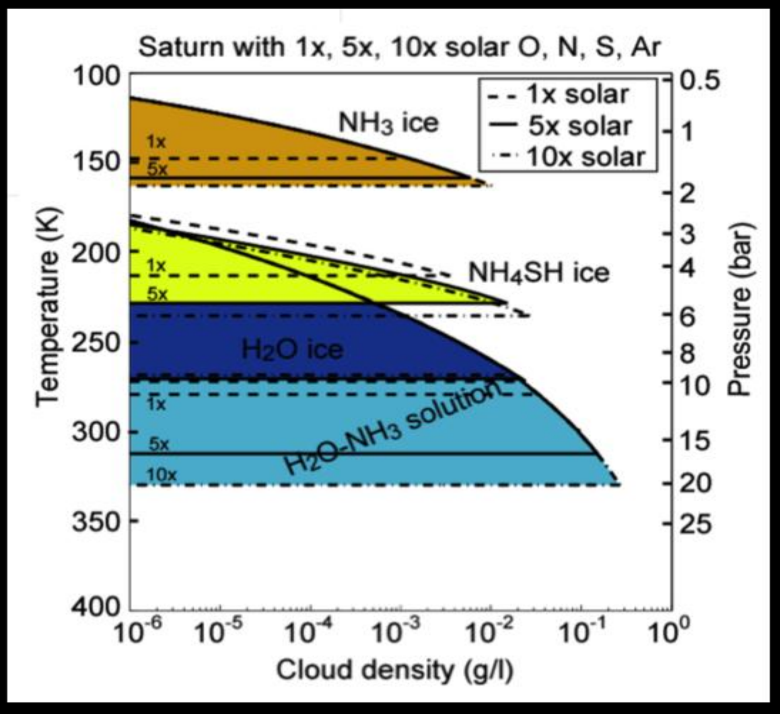
Lower Priority Science Objectives

- determine the vertical profile of zonal winds as a function of depth at the probe entry location(s).
- determine the location, density, & composition of clouds as function of depth in the atmosphere.
- determine variability of atmospheric structure and the presence of clouds in two locations.
- determine the vertical water abundance profile at the probe descent location(s).
- determine precision isotope measurements for light elements such as S, N, and O found in simple atmospheric constituents.

Question of depth

The principal science driver of a Saturn Probe mission is the *bulk* composition of the atmosphere, including the noble gases, He, Ne, Ar, Kr, Xe, and their isotopes; C, O, N, S; and isotopic ratios of D/H, $^{13}C/^{12}C$, $^{18}O/^{16}O$, and $^{15}N/^{14}N$; PH_3 and CO could be diagnostic of deep convection (PH_3) and primordial nature (CO) and may help with the interpretation of the O/H ratio. Noble gases are expected to be well mixed even at 1-bar. The ratios of N/H, S/H, and O/H are found from the volatiles NH_3, H_2O, and H_2S expected to form clouds at varying depths in Saturn's atmosphere. Well-mixed abundances are expected below the cloud condensation bases determined from an equilibrium cloud condensation model (ECCM).

The figure shows cases with elemental abundances 1x, 5x, and 10x solar [2, 3]. To date the only reliable measurement of an element at Saturn is carbon from Cassini measurements of CH_4 [4]. Data from VLA [5] and Voyager [6] give a crude estimate of N/H from NH_3, and radio data provides an estimate of S/H from H_2S [7]. Cassini observations also provide P/H from PH_3 in the upper troposphere/stratosphere of Saturn [8]. Since Phosphine (PH_3) is a disequilibrium constituent in the upper atmosphere, the measured P/H value may not represent the value in the deep well-mixed atmosphere.



The Galileo probe determined that the heavy elements are enriched relative to their solar values by a factor of 4 ± 2 in Jupiter's atmosphere [9,10]. Assuming that the formation models of Jupiter and Saturn are similar, roughly uniform element enrichment is expected in Saturn's atmosphere, in which case, all elements in Saturn's deep well-mixed atmosphere would be enriched by approximately 10 assuming measurements of C/H are representative. This enrichment places the base of the NH_3, NH_4SH, and H_2O clouds at 2, 6, and 20 bars, respectively.

Since convective processes could push the well-mixed regions deeper, it is essential to go well below the ECCM cloud bases to access the well-mixed condensible volatiles, perhaps as deep as 4-5 bars for NH_3, 10-12 bars for H_2S and 30-50 bars for H_2O. Although a probe to 10 bars may fail to reach well-mixed H_2O, it should still be possible to measure the gradient in the H_2O profile and the D/H ratio in H_2O. When combined with measurements of PH_3 and CO, the H_2O gradient profile could enable the determination of the O/H ratio.

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